Information provision and financial incentives in Catalonia's public primary care (2010–2019): an interrupted time series analysis

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Summary

Background The relative efficacy of information provision versus financial incentives in improving primary care quality remains a critical, unresolved question. We investigated these two strategies in Catalonia's public primary care system from 2010 to 2019: an innovative online platform providing real-time quality indicator information and targeted economic incentives for achieving indicator goals.

Methods We conducted a comprehensive interrupted time series regression analysis on data from 272 primary care practices (5,628,080 patients). This analysis used linear regression models with Newey–West standard errors, and a sensitivity analysis including logit transformations to address ceiling effects. We evaluated 1) immediate post-intervention changes (step changes) in indicator results and inter-practice variability (coefficient of variation, CV), and 2) shifts in pre-intervention trends (slopes). We scrutinized 39 indicators after rigorous quality control: 23 novel (12 informed, 11 incentivized) and 16 derived from existing incentivized indicators. Robustness checks included 14 consistently incentivized and 10 non-intervened indicators. Overall, we assessed 63 indicators: 18 control, 13 follow-up, 9 quaternary prevention, 7 treatment, 7 diagnosis, 6 screening and 3 vaccination indicators.

Findings Informed indicators showed positive impacts in 75% (9/12) of cases, and incentivized indicators in 64% (7/11) of cases. Incentivized indicators displayed improvements in annual trends ranging from 6.66 to 1.25 percentage points, with step changes up to 8.87 percentage points. Information led to step changes ranging from 19.67 to 1.07 percentage points, along with trend improvements between 1.09 and 0.34 percentage points annually. Both interventions were associated with step reductions in variability (up to −0.18 CV reduction) and significant trend improvements. Derived indicators showed limited improvements in results or variability (31%, 5/16), with minor step increases up to 2.22 percentage points.

Interpretation Our findings reveal that information provision alone can match or even surpass the impact of financial incentives in improving care quality and reducing practice variability. This challenges conventional wisdom and offers a cost-effective, scalable approach to primary care quality enhancement, with far-reaching implications for global health policy.

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Research in context

Evidence before this study

Quality improvement in healthcare systems increasingly relies on two key strategies: information provision and financial incentives on quality-of-care indicators. With a PubMed search for articles published in any language until June 2024, using the terms and variations for "pay-for-performance", "financial incentives", "primary care" and "quality-of-care indicators", as well as "information provision", "information feedback", "non-financial incentives", "primary care" and "quality-of-care indicators" we found various observational cohort studies and meta-analyses. Most evidence of the impact of incentivization on quality-of-care indicators in primary care is generally obtained from the experience with the UK's Quality and Outcomes Framework (QOF). Whether incentivization or information provision have a positive impact on quality-of-care remains questioned, with variable results among studies and positive effects being generally modest and confused with additional measures, such as reputational incentives, training programs, the publication of guidelines or the choice of clinical computing system. Since 2006, Catalonia's public primary care system has implemented an innovative online platform providing real-time quality indicator information for professionals -without public reporting- and targeted economic incentives for achieving indicator goals. By examining the improvements across different indicator groups, this study aimed to disentangle the effects of information provision from those of financial incentives, and to understand whether information feedback can drive improvements independently.

Added value of this study

The present study used data from 92 quality-of-care indicators in the 2010–2019 decade; these correspond to 272 primary care practices, with an average of 5,628,080 registered patients per year. We evaluated 39 indicators after a rigorous quality control: 23 novel (12 informed, 11 incentivized) and 16 derived from existing incentives. In addition, 14 consistently incentivized and 10 non-intervened indicators were included for robustness checks. Results from the analysis revealed that informed indicators (75%, 9/12) showed a marginally higher percentage of positive impacts than incentivized ones (64%, 7/11). Subsequent incentivization of informed indicators yielded no additional gains. Derived indicators showed limited improvement (31%, 5/16), while robustness checks including consistently incentivized (14%, 2/14) and non-intervened indicators (0%, 0/10) demonstrated minimal positive changes on results and variability due to unexpected factors.

Implications of all the available evidence

Our findings demonstrate that both informing and incentivizing indicators are powerful tools for enhancing quality-of-care metrics and homogenizing clinical practice in primary care, ultimately promoting care equality. The effectiveness of informing via an online platform suggests this could be a cost-effective strategy for quality improvement. We also provide evidence underscoring the importance of strategic indicator selection in information and incentive schemes, offering valuable insights into how the impact of these measures varies based on indicator creation methods. These results have significant implications for healthcare policy and management: they provide a rational foundation for optimizing information and incentive scheme designs, potentially leading to more cost-effective and scalable quality improvement strategies in primary care.

Introduction

Quality improvement in healthcare systems increasingly relies on two key strategies: information provision and financial incentives. Pay-for-performance (P4P) is a widely implemented and studied financial incentive strategy that involves compensating health providers based on the quality of care they deliver,[1–3] with the UK's Quality and Outcomes Framework (QOF) serving as a prominent example.[3–5] P4P is often implemented alongside information provision[2]; in the UK's QOF, all quality of care information was made publicly available, creating a reputational incentive as an additional extrinsic reward.[4,6] This highlights the complexity of the interplay between financial incentives and information provision: the former aims to align professional behavior with organizational goals through extrinsic rewards, while the latter can leverage intrinsic motivation from self-assessment and also drive behavior changes based on reputational concerns.[4,7] The relative effectiveness of these approaches, their potential synergies, and long-term impacts remain subjects of debate in healthcare policy circles. As healthcare systems globally grapple with the challenge of improving quality while managing costs, understanding the optimal balance between information-based and incentive-based approaches becomes crucial.

Previous studies on P4P schemes have shown mixed results, with improvements often modest, more pronounced in process measures than in clinical outcomes,[1–3,8,9] and generally limited to targeted indicator sets.[10–14] Additionally, the effectiveness of P4P schemes is evolving slowly, with no significant evidence of improvements in their design and evaluation over the years.[15] This underscores the need for further research into incentive schemes, particularly focusing on specific aspects of P4P design that can influence physicians' behavior and health outcomes, such as the selection of an appropriate set of quality indicators. Moreover, the concurrent implementation of multiple improvement initiatives has made it difficult to isolate and understand the effects of P4P interventions.[2,4,7,16] Although some studies suggest that non-financial incentives (e.g., education, training, reputational) have the potential to induce long-term practice changes where financial incentives may not,[6,17] further research into non-financial methods and their combination with P4P schemes is necessary to clarify their relative contribution.[18,19]

Since 2006, Catalonia, an autonomous community in northeastern Spain with over eight million inhabitants, has implemented a comprehensive quality improvement scheme in its primary care system. The Catalan Health Institute (ICS), serving nearly 80% of the population across 272 primary care practices (PCPs), utilizes the Quality-of-Care Standard (EQA) framework, comprising 118 evidence-based clinical indicators.[20] At the core of this system is an online platform for health professionals, which provides real-time access to their EQA indicator results and lists of patients not meeting specific criteria. This platform is designed to foster self-assessment and intrinsic motivation for quality improvement by enabling professionals to monitor their performance and compare it with peers (including the average results of their PCP, similar PCPs, and regional averages). Unlike UK's QOF,[4] these results are not publicly reported, thereby reducing the impact of reputational concerns. Concurrently, the Management By Objectives (DPO) scheme offers financial incentives for meeting specific EQA targets, representing a classic P4P strategy. The introduction of indicators into these schemes over time creates a natural experiment to examine the individual and combined effects of information and incentivization within the same healthcare system, by analyzing indicators that were simultaneously informed and incentivized, those only ever informed, and those initially informed and later incentivized.

This study examined the Catalan health system, which uniquely employs both information provision to professionals and P4P. We gather evidence-based insights disentangling the effects of information provision from those of financial incentives and seek to understand whether financial incentives provide incremental benefits beyond information alone, and whether information feedback can drive improvements independently. We explored improvements not only in magnitude (quality of care) but also in consistency across practices (care equality), providing insights into which strategies are most effective at standardizing care quality across a region. Such evidence could guide the strategic design of quality enhancement initiatives in primary care systems globally.

Methods

Study design

We calculated EQA indicator results (percentage of achievement) and variability of results (coefficient of variation, CV) in all practices for the period 2010–2019 and selected EQA indicators which were either introduced as informed (via the online platform) or incentivized (informed plus economically incentivized) during that time. We performed Interrupted time series (ITS) regression analysis to search for significant step changes or changes in trend in indicator results and variability. This approach allowed us to detect both immediate impacts, which may result from rapid policy implementations or practice adjustments, and gradual impacts, which could be due to adaptation time, learning curves, or the need for cumulative patient visits to improve indicator results. We further analyzed the ITS results by categorizing indicators as either newly created or derived. Derived indicators were those formed from subsets of existing incentivized indicators' populations or activities during 2010–2019. For instance, EQA3110 ("LDL control in T2DM with high cardiovascular risk"), introduced as informed in 2017, was derived from the previously incentivized EQA0214 ("LDL control in patients with high cardiovascular risk"). We posited that incentives or information might have weaker effects on derived indicators due to higher likelihood of spillover effects, since their results are likely to be influenced by existing incentives on the indicators they are derived from. Using the example above, the incentive on LDL control in patients with high cardiovascular risk might reduce the effect of an incentive on the derived indicator of LDL control in T2DM patients with high cardiovascular risk.

Data sources and indicator calculation

We used data from 92 quality-of-care EQA indicators of the adult population, sourced from the Primary Care Services Information Systems (SISAP) databases. SISAP ensures data coverage across all 272 primary care practices (PCPs) in the Catalan Health Institute, carrying out rigorous validation processes conducted by a multidisciplinary team to ensure the accuracy and reliability of the data, which has been used in multiple studies.[20–23] To ensure higher data quality and consistency, we began our analysis with data from 2010 rather than 2006. This decision was based on the availability of standardized historical records from 2010 onwards. We recalculated all indicator results for 2010–2019 using the current indicator calculation pipeline employed by SISAP.[20,21] This approach ensured consistency in indicator computation across the study period. It involved calculating indicator results for periods before their creation date (when they had not been previously calculated), during which the indicator results were neither communicated to professionals nor used for incentivization purposes. We collected annual measurements, taken on December 31st each year, as this aligns with the annual evaluation period for the P4P scheme. Although healthcare professionals can access the online platform at any time, with results updated weekly, to maintain consistency in our analysis and align with the P4P evaluation cycle, we used the December 31st data point as a representative annual snapshot. Indicator results represent the percentage of eligible patients seen at the primary care practice who received specified care or met defined targets within that year (Supplementary Table S1).

Indicator selection

To ensure the reliability of the 92 re-calculated indicator results, we performed a quality filtering based on three steps: (a) We classified the 92 indicators according to the Spearman's correlation coefficient of the re-calculated results *versus* the original results reported to professionals each year. Indicators were labelled as *good* (average correlation coefficient, $r \geq 0.7$ across the years and year with minimum $r \geq 0.6$, n = 75), *moderate* (average r ϵ [0.6,0.7) and minimum r ϵ [0.5, 0.6), n = 7) or *poor* quality (average $r < 0.6$ and minimum $r < 0.5$, n = 10). Poor quality indicators were discarded (Supplementary Figure S1). (b) We selected indicators whose results were consistently available for PCPs throughout the entire period from 2010 to 2019 (10 indicators with missing historical data during the study period, causing gaps in the time series, were discarded); (c) After applying our criteria, 63 out of 92 indicators (68.5%) were included in the final analyses. We excluded 2010 data for two indicators (EQA0239 and EQA0227) due to incorrect historical records for that year (Supplementary Table S1).

Statistical analysis

For each indicator (Y_i), we adjusted an interrupted time series linear regression model (ITS) using the yearly indicator results (simple average of all PCPs) and coefficient of variation (CV of results in the PCPs), with the following formula,

$$(1) \quad Y_i = \beta_0 + \beta_1 time_i + \beta_2 intervention_i + \beta_3 time_i * intervention_i + e_i$$

where β_0 is the intercept of the pre-intervention trend, β_1 is the trend before the scheme change, β_2 is the step change the first year after the intervention, and β_3 is the change in trend in the post-intervention period. *time* is a numerical variable indicating the year, and *intervention* is a dummy variable indicating whether the indicator was informed or incentivized that year, and e_i is the error term. For the seven indicators which were first informed and later incentivized, the following formula was used,

$$(2) \quad Y_i = \beta_0 + \beta_1 time_i + \beta_2 inform_i + \beta_3 time_i * inform_i + \beta_4 incent_i + \beta_5 time_i * incent_i + e_i$$

where β_4 and β_5 account for the assessment of incentivization effects over the informed period. In this case, *inform* and *incent* are dummy variables indicating whether an indicator was informed ($inform = 1, incent = 0$) or incentivized ($inform = 1$, $incent = 1$). Given the limited number of time points (10 in total) and the minimal evidence of autocorrelation in ACF and PACF plots for most indicators, we used a lag (0) to avoid overfitting and an unreliable estimation of autocorrelation, prioritizing model parsimony. To address potential issues such as heteroscedasticity, we employed Newey–West standard errors. A sensitivity analysis with logit-transformed results was carried out to account for potential ceiling effects.

We assessed intervention effects using two metrics: immediate step change and change in trend post-intervention. Results were summarized by considering the significance of either step or slope changes when reporting the impact of the interventions. Significant improvements in either metric were classified as "positive impact". Significant reductions were labelled "negative impact". Cases with positive pre-intervention trends but no post-intervention step or trend change were termed "baseline improvement". "No effect" was assigned when no significant step or trend changes were observed. Results were further stratified by indicator types to consider potential workload differences among indicators. Analyses were conducted using R (version 4.3.1), with statistical significance set at $p < 0.05$.

Patient and public involvement

While patient and public involvement is valuable in many stages of research, this study analyzed pre-existing administrative and aggregate data from pre-established interventions, which limited opportunities for meaningful engagement. Given the retrospective nature and focus on existing interventions, we opted for not integrating PPI in the study.

Ethical considerations

This study was approved by the Clinical Research Ethics Committee of IDIAP Jordi Gol (reference number 23/160-P).

Role of the funding source

The funding source was not involved in the study design, in the collection, analysis, and interpretation of data, in the writing of the report, or in the decision to submit the paper for publication.

Results

The landscape of incentives and information on quality-of-care EQA indicators

Of the 63 EQA indicators recalculated for 2010–2019, 39 were introduced after 2013 (24 as informed, 15 as incentivized). We analyzed primary care practice data for at least three years prior to their introduction, when these indicators were neither informed nor incentivized (Fig. 1A). Seven diagnostic indicators were introduced as informed in 2013 and were later incentivized in 2015. Fourteen indicators were incentivized pre-2010, while 10 remained neither informed nor incentivized during the study period (Fig. 1A, Supplementary Table S1). Of 19 derived indicators, 12 became informed, four incentivized, and three remained unchanged. Most newly incentivized indicators focused on control (7/15) or quaternary prevention (6/15), while new informed indicators primarily addressed follow-up (8/24), diagnosis (7/24, later incentivized) or control (5/24, Supplementary Table S2).

Our initial explorations revealed compelling trends in primary care performance indicators. Information and incentivization interventions generally led to increased indicator results and reduced variability across practices. Indicators incentivized throughout 2010–2019 showed consistent positive trends, with performance improvements plateauing towards the study's end, suggesting a ceiling effect. In stark contrast, indicators neither informed nor incentivized displayed no consistent trends in results or variability (Fig. 1B, Supplementary Figure S2).

The impact of incentivization on newly introduced indicators

ITS linear regression analysis was used to determine the impact of incentivization and/or information on indicator results (the average percentage of achievement across PCPs) and variability (CV of indicator results) in the period 2010–2019 (Tables 1 and 2, Fig. 2). Of 39 indicators introduced as incentivized or informed after 2010, 29 (74%) showed baseline improvement

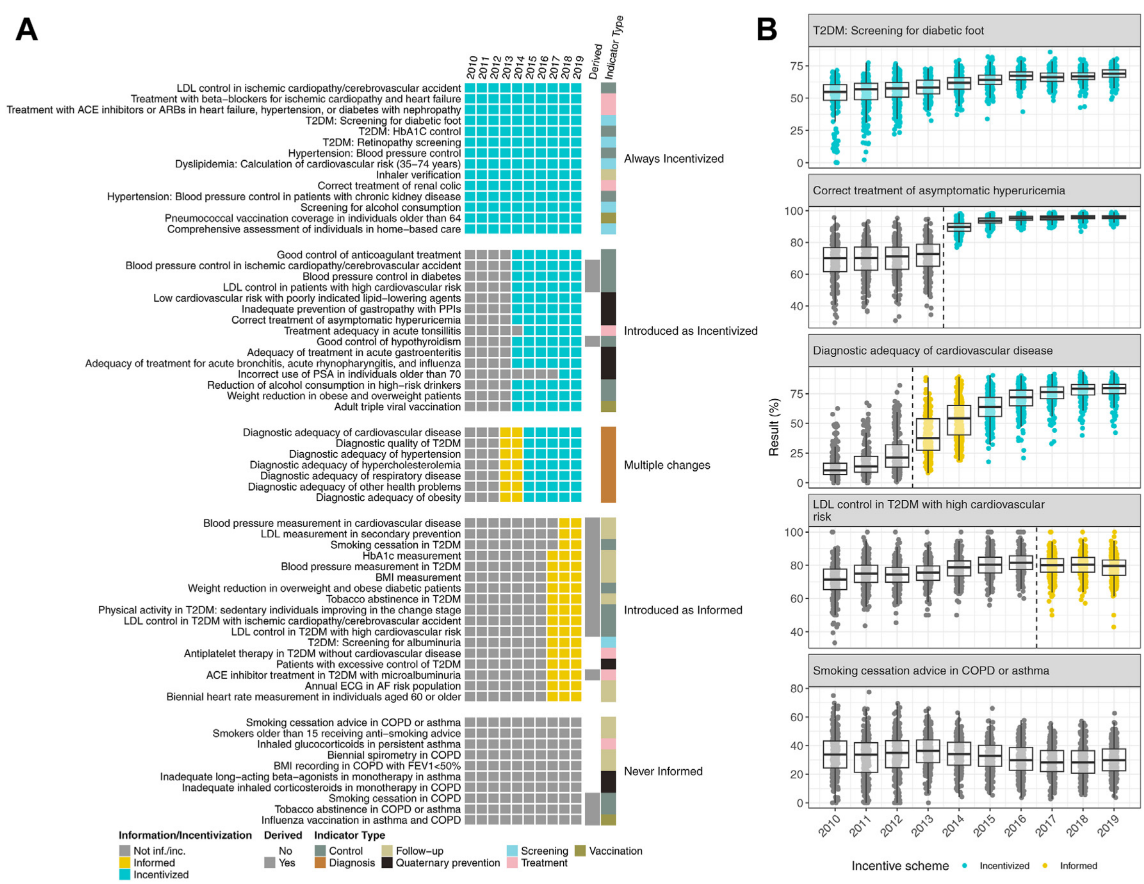

Fig. 1: Landscape of EQA quality-of-care indicators included in the study. **(A)** Heatmap representing the scheme of incentivization and/or information for each of the 63 indicators studied during the period 2010–2019. Indicators are grouped by type of incentive scheme: always incentivized, introduced as incentivized, multiple changes (informed first and later incentivized), introduced as informed and never informed. Each indicator is color-coded in gray if not informed, in yellow if informed and in blue if incentivized. Derived indicators and the indicator type are indicated with the vertical annotation on the right. **(B)** Boxplot representation of the results (percentages of achievement) of 5 example indicators in all ICS primary care practices during the period 2010–2019. An indicator in each scheme category is depicted. The indicator introduction as informed or incentivized is represented with vertical dotted lines.

Indicator	Derived	Scheme change	Year of intervention	Baseline result (%)[b]	Trend before scheme change (% pt change) (95% CI)	Step change (% pt change) (95% CI)	Change in trend (additional % pt change) (95% CI)	End result (%)[b]
Reduction of alcohol consumption in high-risk drinkers	New	Introduced as Incentivized	2014	21.67	1.39 (0.29–2.48)[c]	**19.67 (11.34–27.99)**[c]	−0.7 (−3.14 to 1.74)	46.58
Correct treatment of asymptomatic hyperuricemia			2014	68.64	0.85 (0.51–1.18)[c]	**19.66 (16.6–22.72)**[c]	0.25 (−0.66 to 1.16)	95.75
Adequacy of treatment for acute bronchitis, acute rhinopharyngitis, and influenza			2014	77.73	−0.15 (−0.6 to 0.3)	**2.36 (0.74–3.98)**[c]	**1.09 (0.52–1.65)**[c]	84.52
Inadequate prevention of gastropathy with PPIs[a]			2014	54.66	−0.31 (−0.43 to −0.18)[c]	**−1.48 (−2.5 to −0.47)**[c]	**−1.09 (−1.36 to −0.83)**[c]	45.23
Low cardiovascular risk with poorly indicated lipid-lowering agents[a]			2014	7.55	−0.25 (−0.33 to −0.18)[c]	**−1.07 (−1.55 to −0.6)**[c]	**−0.34 (−0.48 to −0.2)**[c]	2.72
Weight reduction in obese and overweight patients			2014	35.8	−0.06 (−0.83 to 0.71)	−2.86 (−5.42 to −0.31)[c]	**0.89 (0.09–1.68)**[c]	37.29
Treatment adequacy in acute tonsillitis			2015	78	0.73 (0.48–0.97)[c]	−0.85 (−1.78 to 0.08)	−0.27 (−0.64 to 0.11)	83.45
Adequacy of treatment in acute gastroenteritis			2014	97.15	−0.08 (−0.25 to 0.09)	−0.07 (−0.73 to 0.59)	0.16 (−0.02 to 0.34)	97.31
Adult triple viral vaccination			2014	18.49	1.98 (1.9–2.06)[c]	0.1 (−0.48 to 0.68)	−0.78 (−0.94 to −0.62)[c]	32.39
Good control of anticoagulant treatment			2014	91	0.85 (0.44–1.26)[c]	−2.12 (−3.68 to −0.57)[c]	−0.62 (−1.18 to −0.06)[c]	94.35
Incorrect use of PSA in individuals older than 70[a]			2018	20.2	−1.4 (−1.64 to −1.16)[c]	−0.56 (−1.63 to 0.51)	1.21 (0.97–1.45)[c]	10.25
Diagnostic adequacy of hypercholesterolemia		Informed to Incentivized	2015	62.4	2.31 (0.82–3.8)[c]	8.37 (−3.22 to 19.96)	−0.15 (−2.59 to 2.3)	85.3
Diagnostic adequacy of hypertension			2015	46.58	4.61 (4.37–4.86)[c]	5.19 (−4.9 to 15.29)	−1.4 (−3.68 to 0.89)	74.87
Diagnostic adequacy of cardiovascular disease			2015	40.14	12.74 (11.64–13.85)[c]	−2.69 (−12.01 to 6.62)	−8.93 (−10.94 to −6.92)[c]	78.44
Diagnostic adequacy of obesity			2015	71.66	5.32 (4.67–5.96)[c]	2.45 (−3.82 to 8.73)	−3.24 (−4.61 to −1.88)[c]	93.53
Diagnostic adequacy of other health problems			2015	76.54	3.99 (1.86–6.11)[c]	−2.01 (−8.17 to 4.15)	−2.81 (−3.55 to −2.07)[c]	87.36
Diagnostic adequacy of respiratory disease			2015	63.65	6.3 (6.13–6.46)[c]	−2.94 (−6.26 to 0.38)	−5.36 (−6.05 to −4.66)[c]	77.37
Diagnostic quality of T2DM			2015	95.13	0.73 (0.46–0.99)[c]	0.1 (−0.71 to 0.9)	−0.67 (−0.77 to −0.57)[c]	96.99
Diagnostic adequacy of cardiovascular disease		Introduced as Informed	2013	13.53	6.08 (4.98–7.18)[c]	**8.87 (6.32–11.41)**[c]	**6.66 (5.56–7.77)**[c]	52.88
Diagnostic adequacy of hypertension			2013	43.94	−1.09 (−1.33 to −0.85)[c]	**6.02 (5.46–6.58)**[c]	**5.7 (5.46–5.95)**[c]	51.19
Diagnostic adequacy of obesity			2013	55.25	3.37 (2.73–4.01)[c]	**6.59 (5.11–8.07)**[c]	**1.95 (1.31–2.59)**[c]	76.98
Diagnostic adequacy of respiratory disease			2013	50.96	3.12 (2.95–3.28)[c]	**3.41 (3.03–3.79)**[c]	**3.18 (3.01–3.34)**[c]	69.94
Annual ECG in AF risk population			2017	75.85	−3.55 (−5.44 to −1.66)[c]	8.05 (−2.15 to 18.25)	**5.53 (3.6–7.45)**[c]	64.92
Patients with excessive control of T2DM[a]			2017	41.42	1.08 (0.6–1.57)[c]	−2.15 (−4.65 to 0.36)	**−1.25 (−1.74 to −0.77)**[c]	46.2
Diagnostic adequacy of hypercholesterolemia			2013	55.98	1.51 (0.02–3)[c]	1.21 (−2.23 to 4.65)	0.81 (−0.68 to 2.3)	64.71
Diagnostic adequacy of other health problems			2013	58.27	5.67 (3.54–7.8)[c]	0.28 (−4.63 to 5.2)	−1.69 (−3.81 to 0.44)	80.53
Diagnostic quality of T2DM			2013	92.71	0.85 (0.59–1.11)[c]	−0.24 (−0.84 to 0.36)	−0.12 (−0.38 to 0.14)	95.85
T2DM: Screening for albuminuria			2017	53.69	2.37 (1.11–3.63)[c]	−2.92 (−7.02 to 1.18)	−1.22 (−2.54 to 0.09)	73.37
Antiplatelet therapy in T2DM without cardiovascular disease[a]			2017	26.24	−1.54 (−1.68 to −1.4)[c]	2.51 (1.74–3.28)[c]	0.24 (0.09–0.38)[c]	15.25
Biennial heart rate measurement in individuals aged 60 or older			2017	63.77	1.39 (0.81–1.98)[c]	−2.38 (−5.05 to 0.3)	−2.09 (−2.7 to −1.48)[c]	71.25

(Table 1 continues on next page)

Indicator	Derived	Scheme change	Year of intervention	Baseline result (%)[b]	Trend before scheme change (% pt change) (95% CI)	Step change (% pt change) (95% CI)	Change in trend (additional % pt change) (95% CI)	End result (%)[b]
(Continued from previous page)								
LDL control in patients with high cardiovascular risk	Derived	Introduced as Incentivized	2014	59.23	1.27 (0.66–1.89)[c]	**5.03 (1.95–8.11)**[c]	−1.2 (−2.27 to −0.14)[c]	69.04
Blood pressure control in diabetes			2014	72.14	1.74 (1.25–2.22)[c]	0.02 (−2.23 to 2.26)	−1.22 (−1.8 to −0.64)[c]	81.45
Blood pressure control in ischemic cardiopathy/cerebrovascular accident			2014	56.31	3.44 (2.82–4.05)[c]	−1.11 (−3.46 to 1.23)	−2.47 (−3.17 to −1.78)[c]	73.31
Good control of hypothyroidism			2014	54.28	3.95 (3.3–4.61)[c]	1.37 (−0.81 to 3.54)	−2.85 (−3.65 to −2.05)[c]	72.71
ACE inhibitor treatment in T2DM with microalbuminuria		Introduced as Informed	2017	78.39	0.09 (−0.26 to 0.45)	**1.67 (0.28–3.06)**[c]	−1.13 (−1.6 to −0.66)[c]	77.82
Weight reduction in overweight and obese diabetic patients			2017	30.72	−0.79 (−1.11 to −0.48)[c]	**2.22 (0.8–3.64)**[c]	**0.87 (0.52–1.22)**[c]	28.1
Smoking cessation in T2DM			2018	17.81	−0.88 (−1.31 to −0.45)[c]	−0.68 (−3.55 to 2.19)	**1.31 (0.88–1.74)**[c]	10.47
LDL measurement in secondary prevention			2018	65.08	0.81 (0.03–1.59)[c]	−2 (−5 to 1.01)	−0.07 (−0.84 to 0.71)	73.23
Blood pressure measurement in cardiovascular disease			2018	77.07	0.68 (0.12–1.24)[c]	−3.63 (−6.56 to −0.69)[c]	−0.19 (−0.75 to 0.37)	80.14
Blood pressure measurement in T2DM			2017	83.06	0.74 (0.55–0.92)[c]	−2.51 (−3.09 to −1.93)[c]	−0.51 (−0.87 to −0.16)[c]	86.26
BMI measurement			2017	59.71	2.57 (1.88–3.25)[c]	−4.28 (−6.59 to −1.96)[c]	−1.99 (−2.7 to −1.29)[c]	72.82
HbA1c measurement			2017	77	0.98 (0.61–1.35)[c]	−2.17 (−3.41 to −0.94)[c]	−0.4 (−0.8 to −0.005)[c]	84.07
LDL control in T2DM with high cardiovascular risk			2017	70.85	1.68 (1.38–1.99)[c]	−3.24 (−4.5 to −1.98)[c]	−2.14 (−2.75 to −1.52)[c]	78.71
LDL control in T2DM with ischemic cardiopathy/cerebrovascular accident			2017	63.14	1.94 (1.41–2.47)[c]	−3.83 (−5.5 to −2.16)[c]	−0.85 (−1.38 to −0.31)[c]	76.73
Physical activity in T2DM: sedentary individuals improving in the change stage			2017	25.51	6.58 (5.21–7.95)[c]	−3.8 (−10.27 to 2.67)	−9.09 (−12.68 to −5.5)[c]	56.64
Tobacco abstinence in T2DM			2017	81.68	−0.14 (−0.3 to 0.01)	−1.02 (−1.71 to −0.33)[c]	−0.14 (−0.47 to 0.19)	79.65

[a]Inverse indicators (negative step and trend changes represent improvement). [b]Introduced as Incentivized: baseline result 2010, end result 2019; Informed to Incentivized: baseline result 2013, end result 2019; Introduced as Informed: baseline result 2010, end result 2019 (except for diagnostic indicators, 2014); all derived indicators: baseline result 2010, end result 2019. [c]Coefficient different than zero with $p < 0.05$; **bold text** indicates positive impacts.

Table 1: **Interrupted time series (ITS) analysis on average indicator results among ICS primary care practices for the 39 quality-of-care indicators introduced as informed or incentivized after 2013.**

trends before implementation (*Trend before scheme change* in Table 1, Supplementary Figures S3–S4); these improvement tendencies, ranging from 6.58 to 0.25 %-point changes per year, were found in a similar fraction of derived indicators and newly created indicators (12/16, 75% *versus* 17/23, 74%). Eleven of 14 indicators (79%) incentivized throughout 2010–2019 displayed significantly positive result trends, compared to five of 10 (50%) never informed or incentivized (50%; Supplementary Figure S3).

Incentivization positively impacted indicator results or variability in seven of 11 new indicators (64%; 5/6 quaternary prevention and 2/3 control indicators; Fig. 2, Supplementary Figures S4–S6). Four showed significant step increases in results post-implementation (19.67 to 1.07 percentage point changes), while four demonstrated positive trend changes (1.09 to 0.34 percentage point improvements annually). Taken together, incentivization showed positive impacts on the results for six of the 11 indicators assessed (Fig. 2, Table 1, Supplementary Figure S4). Analysis of the variability of results revealed significant step change reductions after incentivization for four indicators (−0.14 to −0.01 CV reductions), and one indicator showed a favorable trend change (−0.03 CV reduction annually; Fig. 2, Table 2, Supplementary Figure S5). Notably, three of four new indicators not positively impacted by incentivization showed significantly positive trends in results and/or variability before intervention (Tables 1–2).

The effect of information without incentivization on new indicators

Evaluation of quality-of-care indicators revealed positive impacts on indicator results and/or variability for 9 out of 12 newly created indicators (75%) after their introduction as informed -not incentivized- via the online platform. This effect was observed across various indicator types: 6/7 diagnosis, 1/1 treatment, 1/1 quaternary prevention, and 1/2 follow-up indicators (Fig. 2, Supplementary Figures S4–S6). Specifically, six of 12 indicators displayed significantly positive changes in the post-intervention trends (6.66 to 1.25 percent point

Indicator	Derived	Scheme change	Year of intervention	Baseline result (%)[a]	Trend before scheme change (annual CV change) (95% CI)	Step change (CV change) (95% CI)	Change in trend (additional CV change) (95% CI)	End result (%)[a]
Reduction of alcohol consumption in high-risk drinkers	New	Introduced as Incentivized	2014	0.52	−0.06 (−0.09 to −0.03)[b]	**−0.14 (−0.24 to −0.04)[b]**	0.06 (0.03 to 0.09)[b]	0.16
Correct treatment of asymptomatic hyperuricemia			2014	0.17	−0.01 (−0.01 to −0.004)[b]	**−0.11 (−0.12 to −0.09)[b]**	0.001 (−0.003 to 0.005)	0.02
Adequacy of treatment for acute bronchitis, acute rhinopharyngitis, and influenza			2014	0.09	−0.004 (−0.005 to −0.003)[b]	**−0.01 (−0.01 to −0.001)[b]**	−1e-04 (−0.002 to 0.002)	0.05
Weight reduction in obese and overweight patients			2014	0.14	−0.004 (−0.01 to −7e-04)[b]	**−0.01 (−0.03 to −0.003)[b]**	0.002 (−0.001 to 0.005)	0.1
Incorrect use of PSA in individuals older than 70			2018	0.33	0.01 (0.01–0.01)[b]	−0.02 (−0.04 to 0.004)	**−0.03 (−0.04 to −0.03)[b]**	0.36
Adequacy of treatment in acute gastroenteritis			2014	0.02	−1e-04 (−0.002 to 0.001)	−0.003 (−0.01 to 0.003)	−4e-04 (−0.002 to 0.001)	0.01
Low cardiovascular risk with poorly indicated lipid-lowering agents			2014	0.32	0.004 (0.002–0.01)[b]	0.01 (−0.01 to 0.02)	−0.003 (−0.01 to 0.004)	0.33
Adult triple viral vaccination			2014	0.39	−0.03 (−0.03 to −0.02)[b]	0.005 (−0.01 to 0.01)	0.01 (0.01–0.02)[b]	0.24
Good control of anticoagulant treatment			2014	0.09	−0.02 (−0.03 to −0.01)[b]	0.03 (−0.01 to 0.06)	0.02 (0.005–0.03)[b]	0.03
Inadequate prevention of gastropathy with PPIs			2014	0.07	0.002 (0.001–0.003)[b]	−0.001 (−0.01 to 0.004)	0.01 (0.01–0.01)[b]	0.12
Treatment adequacy in acute tonsillitis			2015	0.1	−0.005 (−0.01 to −0.003)[b]	0.002 (−0.01 to 0.01)	0.01 (0.005–0.01)[b]	0.09
Diagnostic adequacy of cardiovascular disease		Informed to Incentivized	2015	0.42	−0.12 (−0.15 to −0.1)[b]	0.03 (−0.06 to 0.11)	0.1 (0.08–0.11)[b]	0.1
Diagnostic adequacy of hypercholesterolemia			2015	0.17	−0.02 (−0.02 to −0.02)[b]	−0.02 (−0.07 to 0.02)	0.01 (0.003–0.03)[b]	0.09
Diagnostic adequacy of hypertension			2015	0.22	−0.04 (−0.04 to −0.04)[b]	−0.01 (−0.03 to 0.001)	0.03 (0.03–0.03)[b]	0.09
Diagnostic adequacy of obesity			2015	0.15	−0.05 (−0.05 to −0.04)[b]	0.01 (−0.02 to 0.04)	0.04 (0.03–0.04)[b]	0.02
Diagnostic adequacy of other health problems			2015	0.07	−0.02 (−0.02 to −0.01)[b]	0.01 (−0.01 to 0.03)	0.01 (0.01–0.01)[b]	0.03
Diagnostic adequacy of respiratory disease			2015	0.12	−0.03 (−0.03 to −0.02)[b]	0.01 (−0.01 to 0.03)	0.02 (0.02–0.02)[b]	0.05
Diagnostic quality of T2DM			2015	0.01	−0.003 (−0.003 to −0.002)[b]	−1e-04 (−0.002 to 0.002)	0.003 (0.002–0.003)[b]	0.01
Diagnostic adequacy of cardiovascular disease		Introduced as Informed	2013	0.79	−0.07 (−0.09 to −0.04)[b]	**−0.18 (−0.24 to −0.12)[b]**	**−0.05 (−0.08 to −0.03)[b]**	0.29
Diagnostic adequacy of hypertension			2013	0.24	0.01 (0.01–0.01)[b]	**−0.06 (−0.06 to −0.06)[b]**	**−0.05 (−0.05 to −0.05)[b]**	0.18
Diagnostic adequacy of obesity			2013	0.2	−0.003 (−0.01 to 0)[b]	**−0.04 (−0.04 to −0.03)[b]**	**−0.04 (−0.05 to −0.04)[b]**	0.1
Antiplatelet therapy in T2DM without cardiovascular disease			2017	0.28	0.002 (0.002–0.003)[b]	**−0.03 (−0.03 to −0.02)[b]**	**−0.004 (−0.01 to −9e-04)[b]**	0.27
Diagnostic adequacy of hypercholesterolemia			2013	0.17	0.01 (0.005–0.01)[b]	**−0.02 (−0.02 to −0.02)[b]**	**−0.02 (−0.03 to −0.02)[b]**	0.15
Diagnostic adequacy of respiratory disease			2013	0.16	−0.01 (−0.01 to −0.004)[b]	**−0.02 (−0.02 to −0.01)[b]**	**−0.02 (−0.02 to −0.02)[b]**	0.1
Diagnostic quality of T2DM			2013	0.02	−0.003 (−0.003 to −0.002)[b]	**−0.001 (−0.002 to −7e-04)[b]**	0 (−2e-04 to 2e-04)	0.01
Annual ECG in AF risk population			2017	0.13	0.01 (0.001–0.01)[b]	−0.02 (−0.05 to 0.01)	**−0.02 (−0.03 to −0.01)[b]**	0.14
Diagnostic adequacy of other health problems			2013	0.12	−0.02 (−0.03 to −0.02)[b]	0.02 (0.01–0.03)[b]	0.003 (−0.002 to 0.01)	0.06
Biennial heart rate measurement in individuals aged 60 or older			2017	0.24	−0.03 (−0.03 to −0.02)[b]	0.05 (0.02–0.08)[b]	0.03 (0.02–0.03)[b]	0.09
Patients with excessive control of T2DM			2017	0.17	−0.01 (−0.02 to −0.01)[b]	0.02 (−3e-04 to 0.03)	0.01 (0.01–0.01)[b]	0.11
T2DM: Screening for albuminuria			2017	0.37	−0.04 (−0.05 to −0.02)[b]	0.06 (−9e-04 to 0.11)	0.03 (0.01–0.04)[b]	0.11

(Table 2 continues on next page)

Indicator	Derived	Scheme change	Year of intervention	Baseline result (%)[a]	Trend before scheme change (annual CV change) (95% CI)	Step change (CV change) (95% CI)	Change in trend (additional CV change) (95% CI)	End result (%)[a]
(Continued from previous page)								
Good control of hypothyroidism	Derived	Introduced as Incentivized	2014	0.19	−4e-04 (−0.02 to 0.02)	**−0.11 (−0.16 to −0.06)**[b]	−0.004 (−0.02 to 0.02)	0.05
Blood pressure control in diabetes			2014	0.07	−0.01 (−0.01 to −0.01)[b]	6e-04 (−0.004 to 0.01)	0.005 (0.003–0.01)[b]	0.04
Blood pressure control in ischemic cardiopathy/ cerebrovascular accident			2014	0.11	−0.01 (−0.01 to −0.01)[b]	0.01 (0.002–0.01)[b]	0.01 (0.01–0.01)[b]	0.06
LDL control in patients with high cardiovascular risk			2014	0.14	−0.01 (−0.01 to −0.01)[b]	0.002 (−0.01 to 0.01)	0.01 (0.01–0.02)[b]	0.1
LDL measurement in secondary prevention		Introduced as Informed	2018	0.09	−0.003 (−0.01 to 0)	0.01 (−0.01 to 0.02)	0.003 (−2e-04 to 0.01)	0.06
Smoking cessation in T2DM			2018	0.34	0.001 (−0.01 to 0.01)	0.01 (−0.04 to 0.06)	−0.01 (−0.02 to 9e-04)	0.3
ACE inhibitor treatment in T2DM with microalbuminuria			2017	0.22	−0.01 (−0.01 to −0.01)[b]	4e-04 (−0.02 to 0.02)	0.01 (0.01–0.02)[b]	0.16
Blood pressure measurement in cardiovascular disease			2018	0.07	−0.005 (−0.01 to −0.003)[b]	0.01 (0.004 to 0.02)[b]	0.002 (−4e-04 to 0.004)	0.04
Blood pressure measurement in T2DM			2017	0.06	−0.005 (−0.01 to −0.004)[b]	0.01 (0.01–0.01)[b]	0.003 (0.002–0.005)[b]	0.03
BMI measurement			2017	0.18	−0.02 (−0.02 to −0.01)[b]	0.03 (0.01–0.05)[b]	0.02 (0.01–0.02)[b]	0.09
HbA1c measurement			2017	0.05	−0.004 (−0.004 to −0.003)[b]	0.01 (0.003–0.01)[b]	0.001 (0–0.003)	0.03
LDL control in T2DM with high cardiovascular risk			2017	0.14	−0.01 (−0.01 to −0.004)[b]	0.02 (0.001–0.03)[b]	0.01 (0.01–0.02)[b]	0.09
LDL control in T2DM with ischemic cardiopathy/ cerebrovascular accident			2017	0.13	−0.01 (−0.01 to −0.003)[b]	0.01 (0.002–0.02)[b]	0.002 (−0.001 to 0.01)	0.08
Physical activity in T2DM: sedentary individuals improving in the change stage			2017	0.63	−0.09 (−0.11 to −0.06)[b]	0.14 (0.02–0.26)[b]	0.11 (0.08–0.14)[b]	0.21
Tobacco abstinence in T2DM			2017	0.04	−9e-04 (−0.002 to 0)	0.01 (0.003–0.01)[b]	7e-04 (−8e-04 to 0.002)	0.03
Weight reduction in overweight and obese diabetic patients			2017	0.18	−0.01 (−0.01 to −0.01)[b]	0.02 (0.01–0.02)[b]	0.01 (0.01–0.01)[b]	0.13

[a]Introduced as Incentivized: baseline result 2010, end result 2019; Informed to Incentivized: baseline result 2013, end result 2019; Introduced as Informed: baseline result 2010, end result 2019 (except for diagnostic indicators, 2014); all derived indicators: baseline result 2010, end result 2019. [b]Coefficient different than zero with $p < 0.05$; **bold text** indicates positive impacts.

Table 2: **Interrupted time series (ITS) analysis on the coefficient of variation (CV) among ICS primary care practices for the 39 quality-of-care indicators introduced as informed or incentivized since 2013.**

improvements per year), four of which showed additional step improvements in results after their introduction as informed (from 8.87 to 1.25 %-point increases; Fig. 2, Table 1, Supplementary Figure S4). Analysis on the effects on variability revealed that seven of the 12 informed indicators had a significant step reduction in the CV (from –0.18 to –0.001 CV reductions), and seven of the 12 displayed a significant improvement in the post-intervention trend (from –0.05 to –0.004 CV reductions per year; Fig. 2, Table 2, Supplementary Figure S5). The 3 indicators for which information did not have any positive impact displayed significantly favorable pre-intervention trends (Tables 1–2).

We then examined whether incentivizing could further improve results for indicators already informed. Focusing on seven diagnostic indicators introduced as informed in 2013 and incentivized in 2015 (Fig. 1), we found that information positively impacted results and/or variability in 6 out of 7 indicators (Tables 1–2, Fig. 2). Effects were observed on both results and CV for diagnostic adequacy of hypertension, obesity, cardiovascular disease, and respiratory disease, and on CV only for diagnostic adequacy of hypercholesterolemia and diagnostic quality of T2DM. Comparing CV reduction, the incentivization period showed a median 47% decrease *versus* the informed period, while the information period showed a median 32.7% decrease. This difference was significant ($p = 0.038$, Supplementary Figure S7). However, incentivizing previously informed indicators did not result in significant step changes in results or variability, nor in favorable changes in post-intervention trends (Tables 1–2). These findings suggest that while both information and incentivization strategies can improve indicator performance, the additional impact of incentivization after a period of information may be limited.

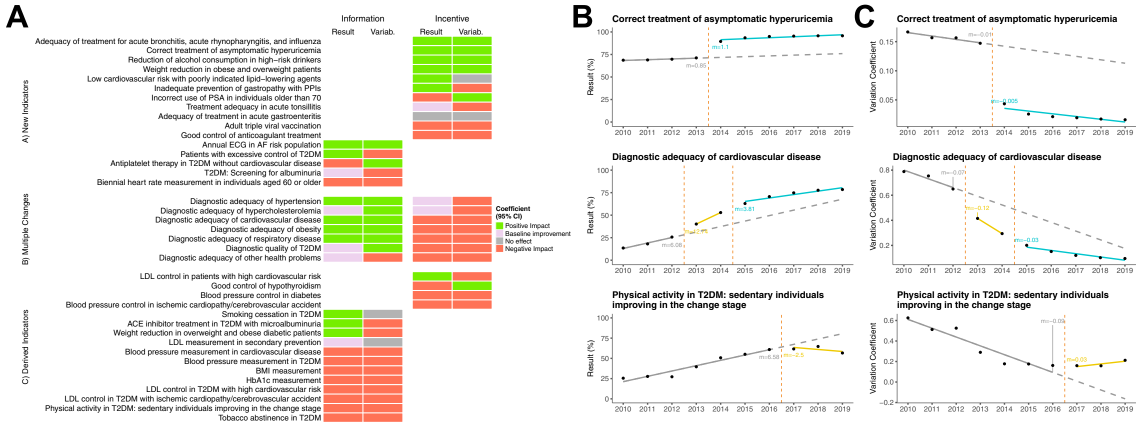

Fig. 2: Summary of results from the interrupted time series regression analysis. **(A)** Summary heatmap of the 39 indicators analyzed with ITS, grouped according to their incentivization patterns. The ITS-derived impact of information and incentivization on results (average percentage of achievement across PCPs) and variability (CV of indicator results) is specified for each indicator. Effects have been classified as *positive*, *negative*, *no effect* and *baseline improvement* (if positive pre-intervention trends remain unaffected post-intervention; see **Methods** for more). **(B, C)** Example ITS analyses on indicator results **(B)** and variability **(C)** in the form of dot plots depicting an example indicator from each of the three heatmap blocks (*new indicators*, *multiple changes*, and *derived indicators*). Linear regression lines are shown for the pre- and post-intervention periods, along with their slopes.

Analyses of indicators derived from other incentivized indicators, those always incentivized, and those never informed nor incentivized

Under the hypothesis of higher likelihood of spillover effects, we separately evaluated information and incentivization effects on 16 indicators derived from other incentivized indicators. Interrupted time series analysis revealed positive impacts on indicator results and/or variability in only five of the 16 derived indicators (31%, 2/9 control and 1/1 treatment indicators; Fig. 2). Post-intervention, one of four incentivized derived indicators (25%) showed a significant step reduction in variability (–0.11 CV reduction for good control of hypothyroidism, Table 2), while two of 12 informed derived indicators (17%) displayed significant step increases in results (2.22 and 1.67 percentage point increases, Table 1). Notably, during the pre-intervention period, 12 of these indicators exhibited significant result improvement trends, and 14 showed significant CV reductions (Tables 1–2, Supplementary Figure S3).

Finally, we assessed unexpected factors impacting indicator results and variability by simulating an intervention in 2014 for the 24 indicators that did not undergo a scheme change during the study period (14 always incentivized and 10 never informed nor incentivized). The ITS analysis revealed positive step changes in the results of two of the 14 always incentivized indicators (14%), one of which also showed a significant improvement in variability. None of the 10 indicators that were never informed nor incentivized showed positive effects (Supplementary Figures S8–S10, Supplementary Tables S3–S4). The effects of information and incentivization on indicator results were validated in a sensitivity analysis accounting for potential ceiling effects (Supplementary Tables S5–S6).

Discussion

This study contributes to the existing literature on primary care quality improvement system by analyzing the impacts of both information provision to professionals and economic incentivization in the unique setting of the Catalan public primary care system. Over an extended period (2010–2019), we assessed a broad range of quality-of-care indicators, distinguishing between newly introduced and derived measures. Using interrupted time series analyses, we examined both average indicator results among primary care practices (PCPs) and result variation. This dual approach allowed us to quantify not only improvements in quality-of-care but also changes in practice homogeneity, reflecting care equality.

Crucially, we separated the effects of merely informing PCPs about indicators from the impact of coupling this information with financial incentives. This distinction provides valuable insights into the relative effectiveness of each strategy in driving quality improvement and reducing care disparities. Additionally, by differentiating between new and derived indicators, we accounted for potential spillover effects, addressing a limitation noted in previous studies of incentive programs like the UK's Quality and Outcomes Framework (QOF).[24]

This study reveals comparable positive effects of both information provision and economic incentivization on new quality-of-care indicators in primary care.

Interrupted time series analysis showed improvements in 64% of incentivized and 75% of informed indicators. However, when assessing the added benefit of incentivization over information alone, no significant improvements were found, though this finding is limited by the short observation period and small number of indicators that could be assessed. Notably, all of these indicators were diagnostic, preventing the analysis of differences between indicator types.

Derived indicators showed limited positive effects from interventions (31%), potentially due to spillover effects from the incentivization of their source indicators.[1] Minimal impacts were observed in continuously incentivized indicators (14%) and none in never informed/incentivized indicators, suggesting a lack of external factors broadly influencing quality measures.

These findings contribute to ongoing discussions about the relative effectiveness of financial incentives *versus* information provision to professionals in improving primary care quality, highlighting the need for nuanced, evidence-based approaches that consider factors like indicator creation methods and prior interventions. Less explored factors, such as differences in indicator types and associated workloads, may also be relevant to the success of the interventions and may require further evaluation.

This study analyzed a decade of data from ICS's information and incentive schemes, evaluating 63 quality-of-care indicators, with 39 undergoing scheme changes. The extended timeframe and diverse indicator set provide valuable insights into the impact of informing professionals via a unified online platform, adding to the existing body of research on non-financial incentives. Even though the follow-up period was truncated in 2019 given the alteration of incentive results during the COVID-19 pandemic,[23] this constitutes a longer period and a relatively larger and more varied number of indicators than most previous studies.[1,2,24–28] The available data allowed us to generate novel evidence on the positive impact of continuously informing professionals via a unified online platform. Like many other studies,[1,2,11,16,29–32] in our analysis context incentivization was accompanied by another intervention (information to professionals). The positive effects that we observed from the incentivized group of new indicators align with some of the evidence available,[8,11–13,30,32–34] although controversy remains on the efficacy of incentivization in health care.[1,2,35,36] Here, we were able to evaluate the added contribution of incentivization on top of information to professionals in a subset of indicators. Furthermore, we differentiated effects on newly created *versus* derived indicators, favoring the notion of avoiding redundancy in the creation of indicator sets.[1,37]

One of the limitations of this retrospective study is that the interventions were implemented in all PCPs from ICS equally; therefore, we did not have results from a control arm of PCPs. Additionally, incentives/information were not given simultaneously for all indicators; some had relatively short post-intervention periods (starting in 2017 or 2018). The limited time points in our study precluded autocorrelation assessment. However, the large population evaluated helped minimize random variation in the data. The exploratory nature of our analysis involved running regressions without multiple comparison corrections for the model coefficient estimates. Due to multiple scheme changes, we included 39 of 92 re-calculated indicators in our analysis of information and incentivization impacts. We re-calculated all indicator results for 2010–2019 to obtain pre-intervention data, excluding those poorly correlated with original results reported to health professionals. Also, 16 indicators were derived from other incentivized indicators and were analyzed separately, and 24 indicators were either consistently incentivized or never informed throughout the study period, providing valuable comparison points. Moreover, while our model assumes persistent effects during the post-intervention period, we recognize this may not hold indefinitely. Another limitation is that the clinical nature and complexity of the indicators may have influenced the outcomes of the interventions. While we attempted to explore this aspect, the limited number of indicators per type restricted our ability to draw robust conclusions, and this remains a subject for further investigation.

In terms of implications for policymakers, our findings suggest that both informing and incentivizing indicators are powerful tools for enhancing quality-of-care metrics and homogenizing clinical practice in primary care, ultimately promoting care equality. The effectiveness of informing via an online platform suggests this could be a cost-effective strategy for quality improvement.

Our research offers crucial insights for policymakers. Newly created indicators show the most significant improvements, while derived indicators are less responsive due to potential spillover effects. This underscores the importance of strategic indicator selection. Policymakers should consider baseline trends and relationships with existing indicators to predict which measures will benefit most from information or incentivization.

To optimize incentive structures, we recommend concentrating rewards on a narrower set of high-potential indicators to maximize the impact of incentivization. Current compensation levels (less than 5% of total salary)[22] may be insufficient compared to other programs.[4,38] Additionally, considering a balance between different types of indicators and recognizing the contributions of various professionals within the team might also be key to promoting teamwork rather than interfering with it.[39] The success of the online reporting platform also underscores the value of transparent, accessible performance data. These evidence-based recommendations offer a roadmap for policymakers to invest in and design more effective, targeted quality improvement initiatives in primary care, potentially achieving greater impacts with optimized resource allocation.

This study raises crucial questions for future research in healthcare quality improvement. Key areas include determining the added value of incentivization over information to professionals alone, assessing the ongoing need for incentivizing long-standing indicators with plateaued results, and identifying which primary care practices and professionals benefit most from these interventions. Such insights could significantly enhance cost-effectiveness estimates and policy decisions.

Our findings provide evidence supporting the implementation of information systems for primary care professionals to monitor their activity, both with and without incentivization. We also offer valuable insights into how the impact of these measures varies based on indicator creation methods.

These results have significant implications for healthcare policy and management. They provide a rational foundation for optimizing information and incentive scheme designs, potentially leading to more cost-effective and scalable quality improvement strategies in primary care.

Contributors

All authors participated in the conceptualization, study and methodology design. REF and EC performed data curation; REF, EC and EH conducted the research and investigation, and REF carried out the formal analysis and visualization of results. EC, EH, LMB, CG, GF, CN and JVA supervised the research activity. REF and LMB carried out the validation of the research outputs. REF wrote the original draft of the manuscript, and EC, EH, LMB, CG, GF, CN and JVA performed its review and editing. GF, CN and JVA were involved in funding acquisition, and CN and JVA participated in the project administration activities.

Data sharing statement

Data from this study will be made accessible upon reasonable request.

Declaration of interests

The authors declare no competing interests.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lanepe.2024.101102.

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